as a teacher at a ridiculously low figure when measured by his training and talent.

He has done and is doing this under the spur of that most intangible but most essential trait of man that we call character, and because of those chimæras of the mind of man that we call ideals. Is he sanely enough balanced to conform his ideals to the trend of the times, to the chance for subordinating them to the broader plans of leadership; or are ideals never ideals when his own mind does not shape them, when from sport—which one pays for, they become work—for which one is paid? And if the zealot who can not modify his view still continues in our midst, as he must, is he to be weeded out; or allowed on sufferance to occupy the waste places of research; or to be kept purposefully from extermination, against a day when the nourishing hand of society may be withdrawn, and zeal in research again becomes synonymous with its primal meaning—devotion with all one's character to one's inborn ideal?

As we, the professionals in science who follow the amateur on to the stage, find ourselves marshalled in the ranks or leading the artisans of science, it may be well to remember that a Galileo, a Newton, a Berzelius and a Darwin lived and worked—not in vain—before the day of organization and intensive team work had dawned!

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THE STRUCTURE OF THE HELIUM ATOM

ACCORDING to the model which Bohr proposed in 1913, the helium atom consists of two electrons moving in a single circular orbit having the nucleus at its center. The electrons remain at the opposite ends of a diameter and thus rotate in the same direction about the nucleus. The angular momentum of each electron is assumed to be $h/2\pi$, where h is the quantum constant. The ionizing potential of helium calculated by this theory is 28.8 volts. Recent experimental determinations by Franck and Knipping have given 25.4 ± 0.25 volts. Bohr's theory is approximately right but does not give the true structure.

For the hydrogen atom and helium ion, atoms containing but a single electron, Bohr's theory seems to be rigorously correct. For atoms containing more than one electron there are many facts which indicate that modifications or extensions are needed.

The chemical properties of the elements, particularly the periodic relationships and the phenomena of valence, have shown definitely that the electrons are not in general arranged in coplanar orbits. According to the theory which I advanced last year, the electrons in their most stable arrangements move only within certain limited regions about the nucleus, each of these cells containing not more than two electrons. The atoms of the inert gases were found to have their cells arranged symmetrically with respect to an equatorial plane, no electrons however ever lying in this plane. According to this view, the two electrons in the helium atom should not move in the same orbit but in separate orbits symmetrically located with respect to the equatorial plane. The two electrons in the hydrogen molecule (and in every pair of electrons which acts as a chemical bond between atoms) must be related to one another in the same way as those of the helium atom.

The most obvious model of this type is one in which the two electrons move in two circular orbits in parallel planes equidistant from the nucleus. By properly choosing the diameters of the orbits, the force of repulsion between the electrons is compensated by the component of the attractive force of the nucleus perpendicular to the plane. This model however proves impossible as it gives a negative value (— 5.8 volts) for the ionizing potential.

A. Landé[1] has recently proposed a model for the eight electrons of an octet in which each electron occupies a cell bounded by octants of a spherical surface. The eight electrons move in such a way that their positions are symmetrically placed with re-

[1] *Verh. d. phys. Ges.*, 21, 653, October, 1919.

spect to three mutually perpendicular planes which pass through the nucleus. When one electron approaches one of these planes it is retarded by the repulsion of the electron on the other side of the plane and is thus prevented from passing through the plane. Although each electron remains within a given octant of the spherical region about the nucleus, yet the momentum of the electron is transferred to the electrons in adjacent cells across the cell boundaries. In this model the momentum travels continuously around the atom in a circular path, being relayed from electron to electron. Thus even though the electrons do not leave their respective cells, the mathematical equations for their motion are very closely related to those which apply to the motions of electrons in circular orbits about the nucleus. Landé's calculations lead to the conclusions that this type of motion is less stable than one in which all eight electrons move in a single plane orbit. This objection can be overcome if we assume that the angular momentum of each electron is $h/2\pi$ instead of the double value which is usually assumed for the electrons in the second shell. In fact, this conception gives grounds for believing that all electrons in their most stable positions in atoms, have orbits corresponding to single quanta and it is only because we have assumed coplanar orbits that we have been led to the conclusion that the outer orbits correspond to increasing numbers of quanta.

This model of Landé's has suggested to me that there should be a similar interrelationship between the two electrons of the helium atom, and also of the hydrogen molecule, and of the pair of electrons constituting the chemical bond.

I assume that the two electrons have no velocity components perpendicular to the plane which passes through the nucleus and the two electrons. The motion is thus confined to a single plane. The two electrons, however, are assumed to rotate about the nucleus in *opposite* directions, and in such a way they are always located symmetrically with respect to a line passing through the nucleus. Consider for example that this line of symmetry is horizontal and that one electron is located directly above the nucleus at a unit distance, and is moving horizontally to the right. Then the other electron will be located at an equal distance below the nucleus and will move in the same direction and with the same velocity. If there were no forces of repulsion between the two electrons, and if we choose the proper velocities, it is clear that the two electrons might move in a single circular orbit about the nucleus, but in opposite directions of rotation. This would require, however, that the electrons should pass through each other twice in each complete revolution. When we take into account the mutual repulsion of the electrons, we see that their initial velocities will suffice to carry them only within a certain distance of each other, and they will then tend to return in the general direction from which they came. With properly chosen initial conditions the electrons will return back exactly on the paths in which they advanced and will then pass over (towards the left) to the other side of the nucleus and complete the second half of an oscillation. Each electron has its own orbit which never crosses the line of symmetry. The orbit however does not consist of a closed curve, but a curved line of finite length along which the electron oscillates.

Unfortunately the equations of motion for this three-body problem are difficult to handle and I have only been able to determine the motion by laborious numerical calculations involving a series of approximations. These however, can be carried to any desired degree of accuracy. By four approximations I have been able to calculate the path and the velocities, etc., to within about one tenth per cent. It is to be hoped that a general solution of this special type of three-body problem may be worked out, if indeed one is not already known to those more familar with this type of problem.

The results of this calculation show that the path of each electron is very nearly an arc of an eccentric circle, extending 77° 58′ each

way from the mid-point (as measured from the nucleus). If we take the radius vector at the mid-point to be unity then the radius at the end of the arc is 1.138. The angular velocity of the electron at the mid-point of the path is such that if it continued with this velocity it would travel through 105° 23′ during the time that it actually takes to move to the end of its orbit (*i. e.*, through 77° 58′).

By imposing the quantum condition that the angular momentum of each electron at the mid-point of its path shall be $h/2\pi$, it becomes possible to calculate the radius vector and the velocity in absolute units. The radius vector for the electron at its mid-point is 0.2534×10^{-8} cm. which is 0.8359 of the radius of the orbit of Bohr's model (0.3031×10^{-8} cm.). Even at the end of the orbit the radius (0.2882×10^{-8} cm.) is less than that of the Bohr model. The angular velocity at the mid-point is 1.431 times that of electrons of the Bohr atom. The number of complete oscillations per second is 24.63×10^{15}, which is 1.222 times as great as the number of revolutions in the Bohr atom (20.16×10^{15} per second). The total energy (kinetic plus potential) of the oscillating atom is 0.9615 of that of the Bohr atom. The ionizing potential of helium according to the new model should be 25.59 volts which agrees with Franck and Knipping's experimental determination within the limits of error given by them, but differs from the 28.8 volts given by Bohr's theory by nearly ten times the experimental error.

The oscillating model is thus not only satisfactory from a chemical point of view but is in quantitative agreement with the properties of helium. The fact that there can be no corresponding structure with three electrons is in accord with the fact that lithium (which has three electrons) is an element having totally different properties from helium.

The calculation for the hydrogen molecule involves greater difficulties. Bohr's model with the two electrons moving in a single circular orbit gives a heat of dissociation of about 63,000 calories, whereas experiment gives about 90,000. The calculations for helium have shown that the radius of the oscillating atom is considerably smaller than that of the Bohr atom, so that the force of attraction between the electrons and the nucleus is much (20 per cent. or more) greater. In the hydrogen molecule this increased force may result in drawing the two nuclei closer together thus increasing the stability of the molecule. Calculations of the orbits of the electrons in the hydrogen molecule are in progress.

The final results with a description of the methods of calculation will be published probably in the *Physical Review* and the *Journal of the American Chemical Society.*

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June 5, 1920

ALFRED WERNER[1]

ALFRED WERNER, professor of chemistry in the University of Zurich, died on November 15, 1919, at Zurich, Switzerland.

Professor Werner was elected an honorary member of the American Chemical Society at the general meeting held in New Orleans, La., April 1, 1915. It is now desired to leave upon the permanent records of this society a tribute to his genius and indomitable energy, and to the wealth of the contributions which he made to our science.

Born at Mulhausen in Alsace on December 12, 1866, he was educated at the technical schools of Mulhausen, Karlsruhe, and Zurich. Later he studied with Berthelot at Paris.

His first published work of note was upon the stereoisomerism of organic compounds containing nitrogen. Applying these theories to the unclassified mass of complex inorganic ammonia compounds, he realized the inadequacy of accepted ideas of valence to explain their constitution. Largely from a study of isomers among these complexes, whose consti-

[1] Tribute prepared by a committee of the American Chemical Society consisting of C. H. Herty, H. L. Wells and Arthur B. Lamb.